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# Commentary

# Combining sustainable agricultural production with economic and environmental benefits

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Two paradigm shifts in agriculture that are taking place that provide important benefits to farmers and to the environment. Conservation Agriculture involves minimising soil disturbance by avoiding tillage operations; maintaining a continuous soil cover of plants and mulch; and cultivating diverse plant species. Together, these practices protect soils against erosion and desiccation; increase soil organic matter contents that in turn increase soil moisture and nutrient supplying capacities; reduce farmers' costs of cultivation; reduce chemical pollution of rivers and groundwater from run-off and leaching of fertilisers; and increase carbon sequestration. The System of Rice Intensification (SRI) involves growing rice in an aerated soil instead of in flooded paddies. Single young seedlings are planted at regular wide spacing, and the soils kept moist but not wet throughout the growing period. Combined with placement of plant nutrients, this practice increases crop yields; reduces costs of land preparation and seed, fertiliser and water use; and reduces methane emissions.

KEY WORDS: no-till farming, rice cultivation, soil conservation

Few geographers and environmentalists in the UK appear to be aware of two relatively new farming systems – Conservation Agriculture and the System of Rice Intensification that are spreading in many countries and which simultaneously reduce farmers' costs of production, increase crop yields and provide important environmental benefits. The geographical and social aspects of these systems deserve more study as well as their economic, environmental and institutional aspects.

## Conservation Agriculture

Soil conservation measures were developed after the North American dust bowl disaster in the 1930s. The first measures involved practices such as contour ploughing, terracing and/or strip cropping to reduce run-off and soil erosion. According to Derpsch (2004), research on 'conservation' or reduced tillage with early versions of a chisel plough was initiated in the Great Plains in the 1930s to alleviate wind erosion. Stubble mulch farming was also developed, and can be seen as a forerunner of no-tillage farming. This collection of practices led to what became known as conservation tillage

The book *Ploughman's folly* by Edward Faulkner (1943) was an important milestone in the development of conservation agricultural practices. Faulkner questioned the wisdom of ploughing and explained the destructive nature of soil tillage. He stated: 'No-one has ever advanced a scientific reason for plowing'. Further research in the UK, USA and elsewhere during the late 1940s and 1950s made no-tillage farming possible, and the practice began to spread in the USA in the 1960s, and in Brazil, Argentina and Paraguay in the 1970s. In 1973, Shirley Phillips and Harry Young published the book *No-tillage farming*, the first of its kind in the world, and this was followed in 1984 by the book *No-tillage agriculture: principles and practices* (Phillips and Phillips 1984).

The modern successor of no-till farming – now generally known as Conservation Agriculture (CA) – goes much further. It involves the simultaneous application of three practical principles based on locally-formulated practices (Friedrich *et al*. 2009; Kassam

**Table 1** Area under CA by continent

| Continent/region | Area (ha) | Percent of total |
|---|---|---|
| South America | 55 464 100 | 45 |
| North America | 39 981 000 | 32 |
| Australia & New Zealand | 17 162 000 | 14 |
| Asia | 4 723 000 | 4 |
| Russia & Ukraine | 5 100 000 | 3 |
| Europe | 1 351 900 | 1 |
| Africa | 1 012 840 | 1 |
| **World total** | **124 794 840** | **100** |

*Source*: FAO-CA website (http://www.fao.org/ag/ca/6c.html)

*et al*. 2011a): minimising soil disturbance (no-till seeding); maintaining a continuous soil cover of organic mulch and plants (main crops and cover crops including legumes); and cultivation of diverse plant species that, in different farming systems, can include annual or perennial crops, trees, shrubs and pastures in associations, sequences or rotations, all contributing to enhance system resilience[1]. CA, in conjunction with good crop, nutrient, weed and water management, is at the heart of FAO's new agricultural intensification strategy (FAO 2011). Worldwide, CA is now practised on an estimated 125 million ha, mainly in North and South America, and in Australia, but also increasingly in China, Kazakhstan, Ukraine and Russia (Table 1). During the past decade, it has begun to spread in Asia more generally (including on the Indo-Gangetic Plains), in Europe (including in the UK) as well as in Africa. CA has now spread over 1 million ha in Africa, including in South Africa, Mozambique, Zambia, Zimbabwe, Madagascar, Kenya, Sudan, Ghana, Tunisia and Morocco, and some two-thirds of the area is under small-holder production. Much of the latter adoption has occurred in the past 4–5 years as a result of more extension attention and development resources being directed towards the promotion of CA through participatory dissemination approaches.

No-till farming was introduced as a means to control soil erosion and sustain crop production on erodible or degraded soils, and it has been promoted mainly for that purpose. However, during the past decade, CA has become the flagship of an alternative agricultural paradigm for intensifying crop production that not only improves and sustains productivity but also delivers important environmental services (Kassam *et al*. 2009 2011a; FAO 2011). The elimination or minimisation of mechanical soil disturbance avoids or reduces the shattering of topsoil structure and pores, loss of soil organic matter and soil compaction which occur with tillage and which thereby contribute to decreased infiltration and increased waterlogging (Plate 1), run-off and soil erosion, decreased soil moisture-holding capacity and rooting volume, and degradation of soil health and productive capacity. Maintaining a continuous cover of plants and organic mulch protects the soil against the direct impact of rain drops, enables more rainwater to enter the soil and eliminates evaporation of moisture from bare soil. The build-up of soil organic matter from plant residues left on the soil surface – aided also by their protecting the soil surface against desiccating hot sunshine and wind – improves soil structure and porosity which, in turn, increase soil moisture absorption and storage capacities. Covering soil with organic mulch also increases the numbers of soil micro-organisms and meso-fauna, particularly earthworms, that help to break down plant remains and incorporate them in the soil, thereby making their nutrient content available to plant roots and creating biopores of various sizes that improve both soil water-holding capacity and soil drainage. The use of deep-rooting leguminous crops in rotations or as intercrops can further increase soil porosity as well as provide free nitrogen to soils.

Perhaps of greater immediate relevance to farmers and governments in current straitened economic times, CA also provides considerable economic benefits. The elimination of mechanical tillage and weeding greatly reduces costs of cultivation, and less fertiliser can be used when it is placed in the soil at the time of planting instead of being broadcast on the soil surface. CA is scale-neutral in the sense that the same production and conservation objectives can be achieved by big, medium and small farmers, using labour and technology relevant for their particular scale of operations. In Zambia, Aagaard (2011) reported that direct seeding with an animal-drawn ripper-seeder with a knife or chisel soil opener for line-sowing and fertiliser placement takes 4 h per hectare compared with 14 h for conventional ploughing (Plate 2); and farmers using tractors can prepare 1 ha in 1 h and reduce fuel consumption from 15 to 6 litres/ha. The latter is an important economy measure in parts of Asia where tractor cultivation is increasingly being practised. Minimum soil disturbance practices using hand implements can reduce labour input by 90%. This reduced drudgery is particularly important in areas where farming is mainly practised by women or elderly farmers, or those suffering from HIV/AIDS.

These time economies enable farmers to plant crops more nearly on time, which can greatly increase yields and security of production (Aagaard 2011). By increasing soil organic matter contents and moisture-holding capacity, CA can double subsistence crop yields in areas where use of fertilisers is uneconomic and it can sustain production in years with low rainfall (Silici *et al*. 2011; Marongwe *et al*. 2011). In Karatu District, Tanzania, where CA was introduced in 2005, average yields of maize increased from 1 t/ha to 6 t/ha using only farmyard manure as a fertiliser (FAO 2011; Owenya *et al*. 2011). The promotion of CA in


**Plate 1** Soil compaction and loss in water infiltration ability caused by regular soil tillage leads to impeded drainage and flooding after a thunder storm in the ploughed field (right) and no flooding in the no-till field (left). Photograph taken in June 2004 in a plot from a long-term field trial 'Oberacker' at Zollikofen close to Berne, Switzerland, started in 1994 by Swiss No-till. The three water filled 'cavities' in the no-till field derive from soil samples taken for 'spade tests' prior to the thunder storm
*Source*: Wolfgang Sturny

**Plate 2** Direct seeding into mulch with animal drawn ripper-seeder in Zambia
*Source*: Josef Kienzle

sub-Saharan Africa could greatly reduce malnutrition and poverty, the risk of famine and migration to urban areas or internationally. It deserves greater support from national governments, international aid agencies and NGOs.

In addition to these economic benefits, CA also provides considerable environmental benefits (Kassam *et al*. 2011a). Not only does CA prevent soil erosion and help to bring degraded soils back into production but it can also greatly reduce deforestation and burning of savannah vegetation in areas where shifting cultivation is practised. Integrating CA practices into shifting agriculture can help to transform it from 'slash and burn' farming to a 'slash and mulch' system with potential for enhancing soil productive capacity and agricultural production over time. In areas of intensive agriculture, CA greatly reduces or eliminates chemical pollution of rivers and groundwater caused by fertiliser run-off and leaching that can occur under customary intensive practices. It also reduces emissions of carbon dioxide, methane and nitrous oxide to the atmosphere (Parkin and Kaspar 2006; Baig and Gamache 2009; Ceja-Navarro *et al*. 2010). In fact, by increasing soil organic matter contents, it increases carbon sequestration (West and Post 2002; CTIC/FAO 2008; Reicosky 2008; Baig and Gamache 2009).

CA does not provide a solution to all farming problems, although it does offer an alternative approach to underpin sustainable crop production systems. Like any farming system, CA has its constraints that must be overcome (Friedrich and Kassam 2009). The establishment of CA methods can be difficult in the initial years in some semi-arid areas and on heavy clays, compacted soils and poorly drained land. Control of pests and diseases can be difficult in some instances where crop residues are left on the soil, and pesticides/herbicides may need to be used, at least in the initial years. Leaving crop residues on fields as mulch would eliminate an important source of animal fodder in areas where livestock play an important role in farm economies. On larger farms, the lack of appropriate equipment for seeding and fertiliser placement through surface mulches can be problematical.

None of the above problems are insoluble. The negative effects of difficult biophysical conditions can be reduced as new, improved, soil physical and biological conditions are established through CA practices, and diversified crop rotations and associations can keep crop pest/disease risks low. Weed control is easier where hand cultivation is practised; and the use of an initial herbicide application followed by crop rotations and maintenance of a continuous soil cover by plants and mulch can eventually reduce weed competition. In CA systems with livestock husbandry, total biomass production is increased over time so that it is possible to manage residue allocation between livestock feed and soil protection dynamically. The constraint of lack of suitable mechanical equipment diminishes as a sufficient market develops for the local manufacture and provision of such equipment. What is now needed is more innovative practical research to tackle soil, agronomic and livestock husbandry problems; and initial government subsidies may be justified to make appropriate farm equipment more readily available. The most serious and widespread constraints on extending CA in sub-Saharan Africa – where it is perhaps most urgently needed – are institutional, as discussed in the final section of this paper.

## System of Rice Intensification

The System of Rice Intensification (SRI) represents a paradigm shift in rice cultivation, making a change from the traditional practice of growing the crop in flooded soils to growing it in an aerated soil with different crop and water management. SRI originated in Madagascar following two decades of observations and experimentation (Laulanié 1993), and it was disseminated in Madagascar and further developed with the efforts of Association Tefy Saina (ATS). Initially, the focus was on the changes in production practices that differentiate SRI cultivation from the standard rice culture, and these changes were understood as constituting SRI (Uphoff *et al*. 2011). In 1994, the Cornell International Institute for Food, Agriculture and Development (CIIFAD) began working with ATS in Madagascar. Those two organisations started to promote the knowledge and practice of SRI in Madagascar and other countries in 1997 (CIIFAD 2012). The validity of the SRI methods has now spread to some 50 countries in Asia, Africa and Central America[2].

SRI agronomic and water management practices differ fundamentally from those used in traditional rice systems in which fields are kept flooded either naturally or with irrigation. As reviewed in Uphoff *et al*. (2011), SRI involves planting single, 8–12 day old rice seedlings shallowly at regular $25 \times 25$ cm spacing and keeping the soil moist but not wet throughout the growing period. Fertilisers are placed in the soil at the time of planting, not broadcast wastefully on the soil surface. Crops benefit from more abundant panicle-bearing tillers per plant and per unit area, more seeds per panicle and heavier grains, a larger root system (Plate 3) and from capturing more solar energy, all of which lead to higher biomass production per unit area. The SRI provides many insights into ways that rice production can be increased efficiently and economically by paying more attention to biology and agroecology, summarised in a recent joint publication by Africare, Oxfam America and the WWF/ICRISAT Project (2010).

As with CA, there are considerable economic benefits from adopting SRI practices (reviewed in Kassam *et al*. 2011b). Farmers' costs are greatly reduced by reduced power and labour needed for land preparation and by reduced amounts of seed, fertiliser and irrigation water used. Results of trials in 11 countries showed that yield increases over customary cultivation methods averaged over 60%, though with considerable variation between countries (11–220%) and within countries (38–156% in eight provinces of Indonesia). In China, the country where SRI is now practised most extensively, the average yield of paddy in Zhejiang Province increased by 1.3 t/ha on the 688 000 ha on which SRI methods were used, with 22.6% less irrigation water used. Four studies in India, Indonesia, Kenya and Mali reported production costs reduced by 20–32% and profitability per hectare increased by between 52% and 183%. In Vietnam, a survey of 781 000 farmers using SRI methods showed that only 20% were using the full range of SRI practices, yet those using partial SRI practices had 10–14%

**Plate 3** Stronger, healthier root system with SRI (left) being shown in a farmer's field in West Godavari district, Andhra Pradesh, India
*Source*: Alapati Satyanarayana

yield increases with 30% saving in water and 32% reduction in costs of production. These are important findings. They deserve to be followed up by increased support from national governments, aid agencies and NGOs to extend SRI practices more rapidly, especially among small farmers in mega-population countries such as Bangladesh and Indonesia, and in parts of Africa where rice is grown and demand is increasing rapidly.

As with CA, too, the introduction of SRI techniques also provides important environmental benefits. The more efficient use of fertilisers in aerated soils reduces atmospheric and water pollution that can occur in traditional paddy cultivation, and the change from wetland to dryland cultivation minimises methane emissions. Reductions in fertiliser use reduce the use of fuel for its manufacture and transport, and reductions in the amounts of water used for irrigation reduce the amounts of fuel used to operate pumps. Reductions in irrigation water used for irrigation and cultivation of rice under aerated soil conditions can also reduce arsenic contamination of soils and food crops in areas of South and South-east Asia where groundwater used for irrigation is contaminated with arsenic (Brammer 2009). Additionally, there are potential health benefits to farm workers from working in dryland fields instead of in flooded fields – especially important in countries where filarial diseases are prevalent – and from the reduction of mosquito breeding sites.

Initially, SRI was perceived by some scientists as a labour-intensive methodology for irrigated rice production by small farmers. However, once farmers acquire the required SRI skills, net labour input as a factor of production is reduced by some 15%, with a concomitant increase in labour productivity (Uphoff *et al*. 2011) Also, the earlier controversy surrounding the superior performance of SRI has begun to wane as more research results provide a better understanding of the reasons underlying the improved phenotypic and agronomic performance of rice grown under SRI conditions (Stoop and Kassam 2005; Kassam *et al*. 2011b; Stoop 2011). The SRI principles are being extended to rainfed situations, including in areas where 'upland' rice is direct-seeded, and to other crops such as wheat, finger millet, sugarcane and aubergines. SRI practices are also being used by some farmers using mechanised agriculture in northern India and Pakistan. In Pakistan, too, attempts to combine CA and SRI practices on raised beds in the wheat–rice rotation are being made (Sharif 2011), including with direct seeding of rice instead of transplanting seedlings. The reduced water requirement with SRI – in the range of 30–50% – is particularly advantageous in parts of northern India, Pakistan and China where groundwater supplies have been seriously depleted by excessive use of water for irrigation (Uphoff and Kassam 2011); it would be beneficial in Bangladesh, too, both to farmers and to the government providing subsidies, to reduce the amount of fuel used in tubewell irrigation.

Much remains to be done, both by research institutions and by farmers, to discover how best to adapt SRI principles to different agroecological and cultural environments, both regionally and locally. An example of the latter is the extensive river floodplains in Bangladesh and India where there can be significant differences in soils and hydrological conditions within villages (Brammer 2011). Even in seasonally-flooded environments where rice cultivation under aerated soil conditions may not be possible in the monsoon season, SRI practices such as planting single young seedlings at wide spacing together with fertiliser placement can still increase crop yields; on shallowly flooded land, raised beds can be made on which to grow the crop under aerated conditions; and the cultivation of rice in non-puddled soils enables dryland crops that can be grown in the following dry season to root more deeply. However, conventional flood-irrigated rice may remain advantageous to hard-pressed farmers wanting to grow three crops in a year because of the shorter period that rice seedlings planted at 4–6 weeks spend in the field (although some varieties under the SRI system mature 2 weeks earlier than flood-irrigated counterparts); and weed control in flooded paddies can be easier than with crops grown under dryland conditions.

## Policy and institutional constraints

FAO's recent publication *Save and grow* (FAO 2011) makes a strong case to policymakers for promoting what it terms 'Sustainable crop production intensification' (SPCI) based on CA and precision agriculture practices: CA to help soils to absorb and store moisture, provide plant nutrients, resist erosion and support increased productivity, as described above; and precision agriculture practices to use fertilisers and irrigation water more efficiently and economically. The publication acknowledges that SPCI is knowledge and management intensive, but it does not describe how relevant technical knowledge will be obtained and propagated to promote SPCI. That will provide a serious constraint in the many developing countries where soil, agricultural research and extension services have collapsed or are under-funded and where farmer-driven participatory-learning mechanisms and opportunities are not available to promote adaptive testing and experimentation. Aagaard (2011) makes a blunt appraisal of the institutional desert in which millions of farmers in Africa subsist and a forthright criticism of the wasteful futility of aid programmes that ignore the poor, degraded state of many of the continent's soils. Such institutional constraints – plus others, including intellectual, cultural, biophysical and input constraints that hinder the spread of CA – have been described in Friedrich and Kassam (2009).

*Save and grow* states that a new paradigm of agriculture is needed for sustainable intensive production. The same is true for the research and extension services needed to support CA and precision agriculture, as well as for input supply. Clearly, the old methods of conducting trials and demonstrations in farmers' fields cannot provide every farmer with precise information for his or her individual fields. That is especially so in countries such as Bangladesh and in parts of Africa where farmers may cultivate several small plots in different ecological environments. For precision agriculture, farmers need to be helped to determine appropriate fertiliser and water requirements for their individual fields. Now that there are radios and mobile (cell) phones in most villages, and TV sets and computers in some, distance-learning techniques need to be developed or strengthened that could feed relevant new information directly to farmers or through farmer organisations such as FAO's Farmer Field Schools (Brammer 2011). Methods need to be developed that could enable farmers to test fertiliser and irrigation water requirements on their individual fields (as some farmers in developed countries now do through computer-aided programmes). NGOs, with their closer contacts with rural people than most government officials, could play a valuable role both in testing ideas and in providing feedback.

For geographers and environmentalists, there is scope for much interesting practical research to be carried out on the social, economic and environmental associations and impacts of CA and SRI in different agroecological and cultural settings. It is important to gain a better understanding of potentials and limitations as soon as possible because, in the coming decades, both CA and SRI appear to offer the best hope of increasing food production rapidly, at low cost and without adverse environmental consequences in developing countries where human populations are increasing most rapidly. CA principles can strengthen the sustainability and productivity of most tillage systems (including 'organic' systems) in arable farming, horticulture, plantation agriculture, agro-forestry and integrated crop–livestock systems. Geographically focused studies could help to speed up the planning and provision of better-targeted measures to facilitate the spread and support of relevant new practices.

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## Notes

1 The term CA was adopted during the First World Congress on Conservation Agriculture, Madrid, 2001, organised by FAO and the European Conservation Agriculture Federation. CA is also referred to as no-till or zero-till farming system when no-till is accompanied by direct planting of crop seeds, permanent organic soil cover and crop rotation as defined below by the FAO-based global stakeholder CA Community of Practice Platform (www.fao.org/ag/ca/la.html).

CA is mainly defined by three linked principles which have to coincide in time and space and have to be applied permanently to develop synergies. These principles are:

1 *Continuous minimum mechanical soil disturbance*. This translates into the practice of low-disturbance no-tillage and the respective low-disturbance direct seeding. Soil disturbance has to be avoided as much as possible in all operations, allowing – only in very specific circumstances – disturbance of not more than 25% of the soil surface but not wider than 15 cm bands.
2 *Permanent organic soil cover*. This refers to mulch from crop residues, other organic mulch materials or living crops, including cover crops. The level of soil cover should, ideally, be 100% of the soil surface, but never less than 30%, and should always supply sufficient organic carbon to maintain and enhance soil organic matter levels.
3 *Diversification of crop species grown in sequences and/or associations*. This refers to rotations and sequences of annual crops, mixed-, inter- or relay-cropping, cover crops in perennial orchard or plantation crops, including legumes for their nitrogen benefits as well as for their flowering in support of pollinator populations.

2 For the history of SRI, see http://sri.ciifad.cornell.edu. This web-site currently includes access to a special issue of the journal *Paddy and Water Environment* on SRI: see Uphoff and Kassam (2011). No figures are yet available for the total area under SRI, but it is thought to cover some 5 million ha and to involve 3–4 million farmers.

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